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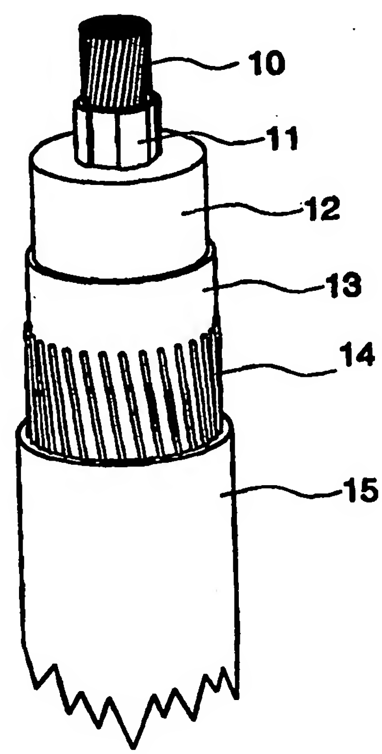
(54) Title: AN INSULATED ELECTRIC DIRECT CURRENT CABLE

(57) Abstract

A DC-cable having at least one conductor and an impregnated insulation system is disclosed. The insulation system comprises a solid electrically insulating dielectric part with a porous, fibrous and/or laminated structure impregnated with an oil that comprises a gelling additive. The gelling additive molecule, which molecule comprises a polar part, group or segment, interacts with the oil and/or any other gelling additive molecule to form a gelled network of longer and/or more branched polymer molecules or cross-linking bridges in the oil, which thereby exhibits the flow properties of a highly viscous and elastic gel.



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AN INSULATED ELECTRIC DIRECT CURRENT CABLE

TECHNICAL FIELD

The present invention relates to an insulated electric device, such as a direct current cable, a DC-cable, a transformer or a capacitor comprising a conductor and an insulation system. The present invention relates in particular to an insulated electric DC cable for transmission and distribution of electric power. The insulation system comprises a porous, fibrous and/or laminated body impregnated with a dielectric fluid.

BACKGROUND ART

Many of the first electrical supply systems for transmission and distribution of electrical power were based on DC technology. However, these DC systems were rapidly superseded by systems using alternating current, AC. The AC systems had the desirable feature of easy transformation between generation, transmission and distribution voltages. The development of modern electrical supply systems in the first half of this century was exclusively based on AC transmission systems. By the 1950s there was a growing demand for long transmission schemes and it became clear that in certain circumstances there could be benefits by adopting a DC based system. The foreseen advantages include a reduction of problems encountered in association with the stability of the AC-systems, a more effective use of equipment as the power factor of the system is always unity and an ability to use a given insulation thickness or clearance at a higher operating voltage. Against these very significant advantages has to be weighed the cost of the terminal equipment for conversion of the AC to DC and for inversion of the DC back again to AC. However, for a given transmission power, the terminal costs are constant and therefore, DC transmission systems are economical for schemes involving long distances, such as for systems intended for transmission from distant power plants to consumers but also for transmission to islands and other schemes with transmission distances where the savings in the transmission equipment exceed the cost of the terminal plant.

An important benefit of DC operation is the virtual elimination of dielectric losses, thereby offering a considerable gain in efficiency and savings in equipment. The DC leakage current is of such small magnitude that it can be ignored in current rating calculations, whereas in AC cables dielectric losses cause a significant reduction in current rating. This is of considerable importance for higher system voltages. Similarly, high capacitance is not a penalty in DC cables.

As in the case of AC transmission cables, transient voltages is a factor that has to be taken into account when determining the insulation thickness of DC cables. It has been found that the most onerous condition occurs when a transient voltage of opposite polarity to the operating voltage is imposed on the system when the cable is carrying full load. If the cable is connected to an overhead line system, such a condition usually occurs as a result of lightning transients.

A typical DC-transmission cable includes a conductor and an insulation system comprising a plurality of layers, such as an inner semi-conductive shield, an insulation body and an outer semi-conductive shield. The cable is also complemented with casing, reinforcement, etc., to withstand water penetration and any mechanical wear or forces during production, installation and use. Almost all the DC cable systems supplied so far have been for submarine crossings or the land cable associated with them. For long crossings the mass-impregnated solid paper insulated type of cable is chosen because there are no restrictions on length due to pressurizing requirements. It has been supplied for operating voltages of up to 450 kV. To date a wound body comprising an essentially all paper tape, i.e. a tape based on paper or cellulose fibers, is used, but application of laminated tape materials such as a laminated polypropylene paper tape is being persued. The wound body is typically impregnated with an electric insulation oil or mass. A commercially available insulated electric DC-cable such as a transmission or distribution cable designed for operation at a high voltage, i.e. a voltage above 100 kV, is typically manufactured by a process comprising the winding or spinning of a porous, fibrous and/or laminated solid insulation based on cellulose or paper fiber followed by the impregnation with the electric insulating oil. The impregnation, which is typically carried out in batches after the insulation has been applied around the conductor, is time consuming and needs to be carefully monitored and controlled. For impregnation of a DC-cable, where several kilometers of cable are impregnated with a typically viscous fluid, the process has a process cycle time extending over days or even

weeks or months. In addition, this time consuming impregnation process is made according to a carefully developed and strictly controlled process cycle with specified ramping of both temperature and pressure conditions in the impregnation vessel used during heating, holding and cooling to ensure a complete and even impregnation of the fiber-based insulation.

A transformer or a reactor for use in a DC-transmission network, at a power generating utility or at a large consumer installation such as an industrial plant also typically comprises porous, fibrous and/or laminated insulating bodies disposed around and between conductors. Typically preformed bodies, such as so called pressboards, manufactured by de-watering and/or pressing a slurry comprising the fibers, are used. The bodies are impregnated by a dielectric fluid to impart the desired electrical properties needed. The impregnation of these bodies in a transformer, although not time consuming, is a sensitive process and specific demands are put on the fluid, the medium to be impregnated and the process variables used for impregnation.

A capacitor exhibits a laminated structure with a dielectric medium comprising one or more polymeric films disposed between two electrodes. Typically, films of polyolefin or thermoplastic polyester are used. The capacitor is typically impregnated with a dielectric fluid. The impregnation of the laminated structure of a capacitor, although not time consuming, is a sensitive process and specific demands are put on the fluid, the medium to be impregnated and the process variables used for impregnation.

The active part of the impregnated insulation systems described in the foregoing is the solid part, such as the cellulose fibers, the polymeric films or any laminate or tape used. The dielectric fluid protects the insulation against moisture pick-up and fills all pores, voids or other interstices, whereby any dielectrically weak air contained in the insulation is replaced by the dielectric fluid.

To ensure a good impregnation result, a fluid exhibiting a low-viscosity is desired. But the fluid shall also preferably be sufficiently viscous at operation conditions for the electrical device to avoid migration of the fluid in the porous insulation, and especially away from the porous insulation. Darcy's law (1) is often used to describe the flow of a fluid through a porous or capillary medium.

$$(1): \quad v = \frac{k\,\Delta P}{\mu\,L}$$

In this law v is the so called Darcy velocity of the fluid, defined as the volume flow divided by the sample area, k is the permeability of the porous medium, ΔP is the pressure difference across the sample, μ is the dynamical viscosity of the fluid and L is the thickness of the sample. Thus, the flow velocity of a fluid within a porous medium will be essentially reciprocally proportional to the viscosity. A fluid exhibiting a low-viscosity or a highly temperature dependent viscosity at operating temperature will thus show a tendency to migrate under the influence of temperature fluctuations naturally occurring in an electric device during operation, and also due to a temperature gradient building up across a conductor insulation in operation, and might result in the formation of unfilled voids in the insulation. As temperature fluctuations and temperature gradients will be expressed in a high-voltage DC cable, any problems associated with migration of the dielectric fluid must also be carefully considered. Unfilled voids or other unfilled interstices or pores will in an insulation operating under an electrical high-voltage direct current field constitute a site where space charges tend to accumulate, thus risking the initiation of dielectric breakdown through discharges which will degrade the insulation and, ultimately, might lead to its breakdown. Thus it is desirable that the ideal dielectric should exhibit a low-viscosity under impregnation and be highly viscous under operation conditions.

Conventional dielectric oils used for impregnating a porous, fibrous or laminated conductor insulation in a DC cable exhibit a viscosity that decreases essentially exponential as the temperature increases. The impregnation temperature must therefore be substantially higher than the operation temperature to gain the required decrease in viscosity due to the low temperature dependence of the viscosity. In comparison, the temperature dependence of the viscosity at temperatures prevailing during operation conditions, is high. Thus, small variations in impregnation or operation conditions might have detrimental effect on the performance of the dielectric fluid and the conductor insulation. Oils are therefore selected such that they are sufficiently viscous at expected operation temperatures to be essentially fully retained in the insulation also under the temperature fluctuations that occur in the electric device during operation, and also that this retention is unaffected of the temperature gradient that normally builds up over a conductor insulation for an electric device comprising conductors at high-voltage. This typically results in a high impregnation temperature to ensure that the insulation will be essentially fully impregnated. However, a high impregnation temperature is disadvantageous as it risks affecting the insulation material,

the surface properties of the conductor and promoting chemical reactions within and between any material present in the device, the insulation of which is being impregnated. Also, energy consumption during production and overall production costs will be negatively affected by a high impregnation temperature. Another aspect to consider is the thermal expansion and shrinkage of the insulation which implies that the cooling rate during cooling must be controlled and slow, adding further time and complexity to an already time consuming and complex process. Other types of oil impregnated cables employ a low viscosity oil. However these cables then comprise tanks or reservoirs along the cable or associated with the cable to ensure that the cable insulation remains fully impregnated upon thermal cycling experienced during operation. With these cables, filled with a low viscosity oil, there is a risk for oil spillage from a damaged cable, therefore an oil exhibiting a highly temperature dependent viscosity and with a high viscosity at operating temperature is preferred.

To impart a suitable increased temperature dependency in the viscosity for a conventional mineral oil, it is known to add and dissolve a polymer, e.g. polyisobuthene, in the oil. This can only be achieved for highly aromatic oils. However, such oils exhibit, poorer electric properties in comparison with more naphtenic oils. These latter are oil types suitable for use as an electric insulation oil. A more aromatic oil must be treated with bleaching earth to exhibit acceptable electric properties. This is costly and there is a risk that small sized clay-particles remain in the oil if not a careful filter- or separation-processing is carried out after this treatment. Alternatively, an oil as disclosed in US-A-3 668 128 comprising additions of from 1 up to 50 percent by weight of an alkene polymer with a molecular weight in the range 100-900 derived from an alkene with 3, 4 or 5 carbon atoms, e.g. polybutene, can be chosen for its low viscosity at low temperatures. This oil exhibits a low viscosity at low temperatures, good oxidation resistance and also good resistance to gassing, i.e. the evolution of hydrogen gas which might occur, especially when an oil of low aromatic content, as the oil suggested in US-A-3 668 128, is exposed to electrical fields. However, the oil according to the disclosure in US-A-3 668 128, although offering a major advance on the traditional electrical insulating oil for impregnation of fibrous or laminated insulations, still suffers the risk of oil migration caused by temperature fluctuations and/or temperature gradients building up under operation as the low viscosity oil is typically not retained during operation at elevated temperatures.

The earlier not yet published International Patent Application PCT/SE97/01095 discloses a DC-cable impregnated with a gelling dielectric fluid, such as an oil. The dielectric fluid comprises a gelling polymer additive that imparts to the fluid a reversible transition between a gelled state at low temperatures and an essentially Newtonian easy flowing state at high temperatures. This substantial transition in viscosity occurs over a limited temperature range. The fluid and the gelling polymer additive must be matched to optimize high temperature viscosity of the easy flowing Newtonian fluid, the low temperature viscosity of the gel and the transition temperature range to suit the desired properties both during impregnation and operation. Such a cable comprising a dielectric fluid matched with a suitable polymer exhibits a substantial potential for reduction of the time period needed for impregnation, but it still requires a strictly controlled temperature cycle during impregnation. The gelling polymer additive and the dielectric fluid are matched or optimized to, in the best way, meet the typically conflicting demands during impregnation and use of the cable. There is a strong desire to reduce impregnation temperatures and at the same time to increase the current densities in the DC-cables, and thus the operation temperatures in the DC-cable. Thus there is a desire to further reduce the gap between the impregnation temperature and operation temperature. Consequently, it will be harder to match the specific demands even with the most sophisticated systems. It must be remembered that not only shall essentially all voids and interstices of the cable insulation be filled by the fluid but the fluid shall also be retained in this insulation as the temperature fluctuates and temperature gradients build up during the operation the apparatus. Suitable gelling systems comprising oils with additions of polymers, but for other purposes, are also discussed in e.g. the European Patent Publication EP-A1-0 231 402, which discloses a gel-forming compound with slow forming and thermally reversible gelling properties intended to be used as an encapsulant to ensure a good sealing and blocking of any interstices in a cable comprising an all solid insulation, such as an extruded polymer based insulation. The slow-forming thermally reversible gel-forming compound comprises an admixture of a polymer to a naphtenic or paraffinic oil and also embodiments using further admixtures of a co-monomer and/or a block copolymer to an oil are considered suitable as encapsulants due to their hydrofobic nature and the fact that they can be pumped into the interstices at a temperature below the maximum service temperature of the encapsulant itself. Similar gel-forming compounds for the same purpose, i.e. the use as encapsulant to block water from entering and spreading along interstices and internal surfaces

in a cable comprising solid polymeric insulations, solid semi-conducting shields and metallic conductors are also known from the European Patent Publications, EP-A1- 0 058 022 and EP-A1-0 586 158.

Thus, it is desirous to provide an insulated electric device, such as a DC-cable, a transformer or a capacitor with an electrical insulation system comprising a porous, fibrous and/or laminated part insulated with a dielectric fluid. In the case of a DC-cable it shall be suitable for use as a transmission and distribution cable in networks and installations for DC transmission and distribution of electric power. The insulation system shall exhibit stable dielectric properties also when operating at high operation temperatures close to the impregnation temperature and/or under conditions where the insulation during operation is subjected to a high voltage direct current field in combination with thermal fluctuations and/or a build up of a substantial thermal gradient within the insulation. The dielectric fluid, typically oil, employed for impregnation shall exhibit a high viscosity index such that it during impregnation has a sufficiently low viscosity, i.e. a viscosity deemed suitable and technically and economically favorable for impregnation, and that it after impregnation has a high viscosity and elasticity, i.e. a viscosity that ensures that the oil during operation will be essentially retained in the porous, fibrous and/or laminated insulation body at all temperatures within the range of temperatures for which the device is designed to operate. The device shall thus in its insulation system comprise an oil with a sufficiently low viscosity prior to and during impregnation to ensure stable flow properties and flow behavior within these ranges, and which exhibits a substantial change in viscosity upon impregnation, i.e. a change in the order of hundreds of Pas or more. An insulated device, such as a DC-cable, impregnated with an oil exhibiting such high viscosity index will provide an opportunity for a substantial reduction in the lengthy time consuming batch-treatment for impregnation of the insulation system, thereby providing a potential for a substantial reduction in the production time and thus the production costs. The reliability, low maintenance requirements and long working life of conventional electric devices, such as DC-cables, comprising an impregnated paper-based insulation shall be maintained or improved. That is, the insulation system shall have stable and consistent dielectric properties and a high and consistent electric strength and, as an extra advantage, open for an increase in the electrical strength and thus allow an increase in operation voltages, improved handleability and robustness of the cable.

SUMMARY OF THE INVENTION

According to the present invention it is an object to provide an insulated electric device comprising a conductor and a porous, fibrous and/or laminated electrical insulation system impregnated with an oil, wherein the desirous features discussed in the foregoing are obtained. This is for an insulated electric device according to the preamble of claim 1 accomplished by the features of the characterizing part of claim 1. Further developments of the device according to the present invention are characterized by the features of the additional claims 2 to 21.

DESCRIPTION OF THE INVENTION

A DC-cable comprising at least one conductor and an impregnated insulation system, where the insulation system comprises a solid electrically insulating dielectric part with a porous, fibrous and/or laminated structure impregnated with an oil is according to the present invention arranged with an oil comprising a gelling additive which exhibits a molecule having a polar part, group or segment. The gelled network of longer and/or more branched polymer molecules or cross-linking bridges in the oil, formed through the gelling interaction between a gelling additive molecule and the oil and/or any other gelling additive molecule, is characterized by the bonds developed in association with the polar part, group or segment of the gelling additive. These bonds will increase the viscosity index of the oil such that the gelled network in the oil of a DC-cable according to the present invention ensures the flow properties of a highly viscous and elastic gel at typical operation temperatures of a DC-cable and lower temperatures. The oil preferably exhibits a thermoreversible transition between a highly viscous elastic gelled state at low temperatures, i.e. typical operation temperatures of a DC-cable and lower temperatures, and a easy flowing liquid state at higher temperatures, i.e. impregnation temperatures. Preferably, the bonds comprised in the gelled network are hydrogen bonds. The gelling additive comprises non polar segments of linear or branched hydrocarbon chains and polar parts, groups or segments. This combination is advantageous as it imparts surfactant properties or a surfactant character to the gelling additive. Thereby the gelling additive has a capability to interact with the solid surfaces with its polar parts and with the oil with its non-polar parts. Of particular interest is the interaction

between the polar parts and the surface of the porous, fibrous and/or laminated structure of many fibrous materials, and in particular cellulose based materials, while the non-polar parts interacts with the oil. This interaction of surfactant character with the solid parts of the insulation and the oil respectively results in an improved wetting which shortens the impregnation time. Whereby the oil penetration into voids and capillary interstices within the porous, fibrous and/or laminated structure can be increased. This surfactant type of interaction between gelling additive molecules and the surface of the porous, fibrous and/or laminated structure and the oil, respectively, will also under other circumstances increase the oil retention within the porous, fibrous and/or laminated structure upon operation at a high temperature, fluctuating temperatures and/or under a substantial temperature gradient. This surfactant type of properties of a gelling additive comprising polar and non-polar parts also provides for a physical bonding of particles to the gelled structure. It is in particular advantageous if dielectrically strong particles with a fine particles size, e.g. in the nanometer range can be incorporated into the gelled structure. Such incorporation of dielectrically strong particles of a fine particle size reinforces the gelled network and the total insulation system both mechanically and electrically.

A prior art DC-cable comprises an oil, e.g. a mineral oil, where the viscosity index is increased by a gelling additive, such as styrene-butadiene block copolymer. The oil viscosity is thereby modified in such a way that the oil can be thermo-reversibly gelled. In this oil, the thermoreversible gelling is caused by partial solubility of the block copolymer in the oil. At low temperatures, only the butadiene blocks are dissolved, whereas the styrene blocks aggregate and micelles are formed. These micelles result in a physical cross-linking of the oil, a gel is formed. As temperature is increased, the stability of the micelles is reduced and, at a certain temperature (the liquid-gel transition temperature), the micelles are disrupted and a liquid-like solution is formed. In contrast, the thermo-reversible gelling of the oil in a DC-cable according to the present invention is governed by other bonding mechanisms, preferably hydrogen bonding. To accomplish this, a DC-cable according to the present invention comprises a gelling additive that introduces hydrogen bonded networks in to the oil. Typically, the gelling additives used in a DC-cable according to the present invention comprise polar segments/groups and non-polar segments. This structure also enables them to function as surfactants. Their surfactant character will, when they are used as gel-inducing additives in impregnants for insulating bodies, enhance the degassing process of the

impregnant, it will also enhance wetting and provide for the physical bonding of particles to the gelled network. The wetting will be enhanced for an insulating body with a polar type of material, at least in its surface, as, for instance, for a cellulose based material, the gelling additives will be attracted to the interface between the non-polar oil and the polar cellulose based material, thus enhancing the wetting process. The same mechanism will provide for the incorporation of fine particles with polar type surface properties into the gelled network. These advantages of the hydrogen-bonding gelling additives or gelators help shorten the impregnation cycle. Another advantage of the systems used in a DC-cable according to the present invention is that their gelling kinetics open for a delayed significantly slower gelling if so desired, this delay can in some cases exceed 24 h. This results in a decreased shrinkage than for a DC cable comprising a gelling impregnant containing a block copolymer as the gelling will occur at a low temperature and while the oil during cooling remains an easy flowing liquid. As a consequence, the "post-filling" step is less problematic.

According to one embodiment the DC-cable comprises an impregnant based on a mineral oil which typically comprises up to 20 % by weight of a gelling additive, or a gelator. Suitable gelators for use with a mineral oil based impregnant comprise;

- a block copolymer comprising a polar block capable of forming hydrogen bonds, such as polyvinyl pyridine added to a content of up to 20 % by weight,
- a block copolymer comprising a polar block capable of forming hydrogen bonds and a non-polar block soluble in the oil added to a content of up to 20 % by weight,
- a urea or di-urea compound added to a content of up to 20 % by weight, preferably in the range of from 1 to 20 % by weight,
- dibensylidene sorbitol added to a content of up to 20 % by weight, preferably in the range of from 1 to 15 % by weight; and/or
- an alkyl-1,3,5-benzenetricarboxamide added to a content of up to 20 % by weight, preferably in the range of from 1 to 20 % by weight, e.g. tri-(3,7-dimethyloctyl)-1,3,5-benzene tricarboxamide added to a content of up to 20 % by weight, preferably in the range of from 5 to 20 % by weight.

According to another embodiment the DC-cable comprises an impregnant based on a vegetabilic oil with a gelator comprising compounds such as a urea or di-urea compound, a cellulose ether and/or ethyl cellulose. Typically the cellulose ether is added to

the oil in the range of from 2 to 10 % by weight and the ethyl cellulose in the range of from 2 to 10 % by weight.

According to a further embodiment the DC-cable comprises an impregnant based on a silicone oil with a gelator that comprises dibensylidene sorbitol in the range of from 1 to 15 % by weight.

The DC-cable according to the present invention typically comprises, from the center and outwards;

- a conductor of any desired shape and constitution, such as a stranded multi-wire conductor, a solid conductor or a sectional conductor;
- a first semi-conducting shield disposed around and outside the conductor and inside the conductor insulation;
- a wound and impregnated insulation according to the present invention with a dielectric electrically insulating solid part exhibiting a porous, fibrous and/or laminated structure as described in the foregoing impregnated with an oil;
- a second semi-conducting shield disposed outside the conductor insulation; and
- an outer protective sheath. Also, the two semi-conducting shields are typically wound and impregnated insulation according to the present invention with a dielectric electrically insulating solid part exhibiting a porous, fibrous and/or laminated structure as described in the foregoing impregnated with an oil. When deemed appropriate, the cable can be complemented with reinforcing and a sealing compound or a water swelling powder for filling any interstices in and around the conductor, other metal/polymer interfaces may be sealed in order to prevent water from spreading along such interfaces.

According to one embodiment the wound cable insulation is pre-treated with the gelator before impregnation. The wound insulation can be soaked in or sprayed with a solution comprising a gelator, dried and thereafter impregnated, but is preferably wound from tapes that are already pretreated with gelling additives. The tapes can have been pretreated already in the line for tape production, but the treatment can of course also have been done in a special treatment operation or in connection with the winding. This is the same for any type of tape, such as an all paper tape, an all polymer tape or a laminated tape of paper and polymeric films or different polymeric films or meshes, webs or nets. Paper tapes can have been coated by spraying or immersing or otherwise contacting the paper with a solution comprising the gelling additive. The gelling additive can have been added to polymeric films,

tapes or the like by spraying or extruding the gelling additive on to the polymer. A coating comprising the gelling additive can also have been co-extruded with the polymeric tape or film. Thus, for a DC-cable comprising such a pretreated insulation, embodiment will ensure that the oil retains its easy flowing essentially Newtonian properties during the essential period of filling phase of the impregnation step and that the gelling additive thereafter, when brought into contact with the oil and at least in part dissolved by the oil, imparts the properties of a highly viscous, elastic gel to oil. The transformation of the easy flowing dielectric fluid to a highly viscous gel can dependent of the combination of gelling additive and dielectric fluid be instant, slow or even delayed. By instant transformation is meant that the transformation is initiated directly as the gelling additive is contacted and dissolved by the dielectric fluid and that the transformation kinetics are such that the transformation is rapid. The slow transformation is also typically initiated directly upon contact between fluid and gelling additive, but the transformation is slowed down by the kinetics of the dissolution and/or transformation. A delayed transformation for up to 24 hours can typically be accomplished by the gelling systems, gelator and matched oil, used in DC-cables according to the present invention.

According to one further embodiment, the gelling additive is unevenly distributed within the insulation such that following impregnation and gelling a viscosity gradient is present in the cable, whereby the viscosity preferably is increased inwards to the conductor. By distributing the gelling additive in this manner within the insulation several important aspects can be improved;

- a more complete filling before start of gelling is ensured also for a gelling system that gels almost instantly;
- a self-healing capability is accomplished, i.e. a damaged part of the insulation can be re-impregnated with fluid from other parts,
- a gelled fluid that retains its highly viscous elastic gelled state also when the temperature around the conductor is raised because of high loads used is obtained.

According to one embodiment of the DC-cable according to the present invention, the cable has an insulation system that comprises a surfactant or blend of surfactants, thereby further enhancing the wetting during impregnation. The surfactant can either be added to the solid part of the insulation prior to impregnation by a pretreatment or it can be comprised in the oil.

To ensure the long term stability of the improved electrical and mechanical properties a gasabsorbing additive is included in the insulating system. A suitable gasabsorbing additive is a low molecular polyiosbutene with a molecular weight less than 1000 g/mole.

A DC-cable according to the present invention is ensured long term stable and consistent dielectric properties and a high and consistent electric strength as good as, or better than for any conventional DC-cable comprising such impregnated porous, fibrous and/or laminated body. This is especially important due to the long life such installations typically are designed for, and the limited access for maintenance to such installations. The special selection and matching of gelling additives, gelators, and oils, impregnants, ensure the long term stable properties of the insulation system also when used at elevated temperatures, at excessive thermal fluctuations and/or under thermal gradients. This opens for a capability to allow an increase in the operation load both in regards of increased voltages and current densities. One further advantage of a DC-cable according to the present invention is that it, due to the surfactant character of the gelators used in DC-cables according to the present invention, opens for a reduction in production time by enhanced wetting, which offers a possible shortened impregnation cycle. Further, the surfactant character of the gelling additive used in a DC-cable according to the present invention provides for a physical bond to polar surfaces such as the surfaces of the porous, fibrous insulation and also to fine dielectrically strong particles which thereby can be incorporated into the gelled structure. Such incorporation of dielectrically strong particles will reinforce and strengthen the insulation both mechanically and electrically. Also the temperature sensitivity during production can be substantially reduced by a suitable selection and matching of oil and gelling additive, which opens for a delayed gelling, and thereby reduced sensitivity of the post-filling step.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention shall be described more in detail under reference to the drawings and examples. Figure 1 shows a cross-section of a typical DC-cable for transmission of electric power comprising a wound and impregnated insulation according to the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS, EXAMPLES.

The DC-cable according to the embodiment of the present invention shown in figure 1 comprises from the center and outwards;

- a stranded multi-wire conductor 10;
- a first semi-conducting shield 11 disposed around and outside the conductor 10 and inside a conductor insulation 12;
- a wound and impregnated conductor insulation 12 comprising a gelling additive as described in the foregoing;
- a second semi-conducting shield 13 disposed outside the conductor insulation 12;
- a metallic screen 14; and
- a protective sheath 15 arranged outside the metallic screen 14.

The cable is further complemented with a reinforcement in form of metallic, preferably steel, wires outside the outer extruded shield 13, a sealing compound or a water swelling powder is introduced in a the interstices in and around the conductor 10.

The insulated electric device of the present invention is applicable for any arbitrary DC-cable with an insulation system comprising a solid porous or laminated part impregnated with a dielectric fluid or mass. The application of the present invention is independent of conductor configuration. It can also be used with DC-cables having an insulation system of this type comprising any arbitrary functional layer(s) and irrespective of how these layers are configured. Its application to DC-cables of this type is also independent of the configuration of the system for transmission of electric power in which the cable is included.

The DC-cable according to the present invention can be a single multi-wire conductor DC-cable as shown in Figure 1, or a DC-cable with two or more conductors. A DC-cable comprising two or more conductors can be of any known type with the conductors placed side-by-side in a flat cable arrangement, or in a two conductor arrangement with one first central conductor surrounded by a concentrically arranged second outer conductor. The outer conductor is typically arranged in the form of an electrically conductive sheath, screen or shield, typically a metallic screen not restricting the flexibility of the cable.

A DC-cable according to the present invention is suitable for use in both bipolar and monopolar DC-systems or installations for transmission of electric power. A bipolar system typically comprises two or more associated single conductor cables or at least one multiconductor cable, while a monopolar installation has at least one cable and a suitable current return path arrangement.

EXAMPLES

In the following, bench tests of some gelling impregnant systems for use in DC-cables according to the present invention are presented.

Example 1

70 g tri(3,7-dimethyloctyl)-1,3,5-benzenetricarboxamide was added to 1 liter of a naphtenic mineral oil. The blend was heated to 100°C under nitrogen atmosphere, N_2, and was then allowed to cool down. A gelling composition with a liquid-gel transition temperature between 50 and 60°C was then formed.

Example 2

12 g of 1-benzyl-3-octyl-urea was added to 1 liter of a naphtenic mineral oil. The blend was heated to 120°C under N_2 and was then allowed to cool down. A gelling composition with a liquid-gel transition temperature of 80°C was then formed.

Example 3

18 g of dibensylidene sorbitol was added to 1 liter of naphtenic mineral oil. The blend was heated to 180°C under N_2 and was then allowed to cool down. A gelling composition with a liquid-gel transition temperature of 100°C was then formed.

These blends or gelling compositions exhibit a development of a stable network and a high liquid-gel transition temperature, in the range of from 50 °C for the system in example 1 to 100 °C for the system in example 3. The results of these examples have shown that with these gelators added to an oil used for impregnation of a conductor insulation in an DC-cable according to the present invention, faster impregnation rates and lower

impregnation temperatures can be employed compared to conventionally used gelling impregnants. Further, a block of bundled paper impregnated with the impregnants described in the examples given in this application behaves like an elastic body at temperatures below the transition temperature and the oil, at these temperatures, is fully retained in the porous, fibrous insulation and between the paper layers. Repeating this last test for oil retention for a conventionally used insulating oil would show a slow flow of oil out from the bundled paper block. Thus, the risk for voids appearing during operation is drastically reduced and the electrical properties for the conductor insulation in a device according to the invention are improved. The improvements related to in the foregoing are likely to result in a cable comprising a wound paper-insulation impregnated with the dielectric system described in the foregoing where essentially all voids in the insulation are filled by the dielectric impregnant, i.e. the insulation is essentially fully impregnated. Such a cable is also likely to, after use at elevated temperatures and high electrical, essentially static fields, exhibit a low number of unfilled voids and thus to be less sensitive to dielectric breakdown.

CLAIMS

1. An insulated electric device having at least one conductor and an impregnated insulation system, wherein the insulation system comprises a solid electrically insulating dielectric part with a porous, fibrous and/or laminated structure impregnated with a dielectric fluid that comprises a gelling additive for interacting with a dielectric oil and/or any other gelling additive molecule to form a gelled network of longer and/or more branched polymer molecules or cross-linking bridges in the oil, which thereby exhibits the flow properties of a highly viscous and elastic gel, **characterized** in that the gelling additive molecule comprises a polar part, group or segment capable of forming hydrogen bonds.

2. An insulated electric device according to claim 1, **characterized** in that the dielectric fluid comprising the gelling additive exhibits the properties of a gelling composition with a thermoreversible liquid-gel transition between a liquid easy flowing state at high temperatures and a highly viscous, elastic gelled state at low temperatures, and that the liquid-gel transition involving a substantial change in viscosity occurs within a narrow, limited range of temperatures.

3. An insulated electric device according to claim 1 or 2, **characterized** in that the gelled network comprises bonds developed by the polar parts of the gelling additive.

4. An insulated electric device according to claim 3, **characterized** in that the gelled network comprises hydrogen bonds formed by the polar parts of the gelling additive.

5. An insulated electric device according to any of claims 1 to 4, **characterized** in that the gelling additive molecule comprises non polar segments of linear or branched hydrocarbon soluble in the dielectric fluid and polar parts, groups or segments.

6. An insulated electric device according to any of claims 1 to 5, **characterized** by a surfactant character accomplished by the polar part of the gelling additive molecule interacting with solid polar surfaces, and the non-polar part of the gelling additive molecule interacting with dielectric fluid.

7. An insulated electric device according to claim 6, **characterized** by the surfactant character of the gelling additive enhancing the wetting of the insulation and increasing the oil penetration into voids and capillary interstices within the porous, fibrous and/or laminated structure upon impregnation.

8. An insulated electric device according to claim 6 or 7, **characterized** by the surfactant character of the gelling additive enhancing the oil retention within the porous, fibrous and/or laminated structure upon operation at a high temperature, fluctuating temperatures and/or under a substantial temperature gradient.

9. An insulated electric device according to any of claims 6, 7 or 8, **characterized** in that the gelled network comprises fine particles with a particle size in the nanometer range incorporated in and physically bonded to the gelled network through the surfactant character of the gelling additive.

10. An insulated electric device according to any of the preceding claims, **characterized** in that the oil is a mineral oil comprising up to 20 % by weight of a gelling additive.

11. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises a urea or di-urea compound

12. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises dibensylidene sorbitol.

13. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises an alkyl-1,3,5-benzenetricarboxamide.

14. An insulated electric device according to claim 13, **characterized** in that the gelling additive comprises tri-(3,7-dimethyloctyl)-1,3,5-benzenetricarboxamide.

15. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises a cellulose based compound.

16. An insulated electric device according to claim 15, **characterized** in that the gelling additive comprises ethyl cellulose.

17. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises a block copolymer comprising a polar block capable of forming hydrogen bonds and a non polar block soluble in the dielectric fluid.

18. An insulated electric device according to any of the preceding claims, **characterized** in that the gelling additive comprises a block copolymer on olefinic block and a block with aromatic rings in its backbone structure.

19. An insulated electric device according to any of claims 1 to 9, **characterized** in that oil is a silicone oil and the gelling additive comprises dibensylidene sorbitol.

20. An insulated electric device according to any of the preceding claims, **characterized** in that the insulation system comprises a surfactant or blend of surfactants.

21. An insulated electric device according to claim 20, **characterized** in that the solid part of the insulation is pretreated with the surfactant.

22. An insulated electric device according to claim 20, **characterized** in that oil comprises the surfactant.

23. An insulated electric device according to any of the preceding claims, **characterized** in that the insulation system comprises a gasabsorbing additive, such as a low molecular polyisobutene.

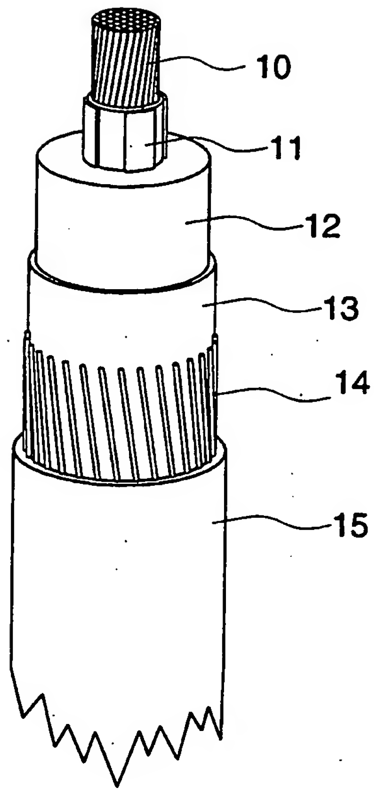

Fig 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 98/02313

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01B3/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	KENJI HANABUSA ET ALL.: "Remarkable Viscoelasticity of Organic Solvents Containing Trialkyl-1,3,5-benzenetricarboxamide and their Intermolecular Hydrogen Bonding" CHEMISTRY LETTERS., no. 5, 1997, pages 429-430, XP002098459 TOKYO JP see abstract ---	

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 March 1999	16/04/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Stienon, P

2

International Application No
PCT/SE 98/02313

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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2

INTERNATIONAL SEARCH REPORT

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Intern···ional Application No
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